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**GEOLOGY, WATER MOVEMENT, AND SEDIMENT
CHARACTERISTICS OF THE SPRING RIVER
UPSTREAM FROM LA RUSSELL,
SOUTHWESTERN MISSOURI**

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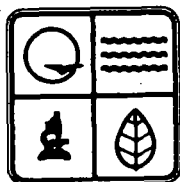
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**MISSOURI DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGY AND LAND SURVEY**

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ABSTRACT

The U.S. Geological Survey and the Missouri Department of Natural Resources, Division of Geology and Land Survey, appraised the geology, water movement, and sediment characteristics in the upstream part of the Spring River basin, to assist the U.S. Environmental Protection Agency in their study of dioxin contamination in the area. The U.S. Environmental Protection Agency has confirmed that the dioxin compound, TCDD (2,3,7,8-tetrachlorodibenzo-*p*-dioxin), is present in the soils, streambed sediments, and fish in the upstream part of the Spring River basin. Although the solubility of dioxin is small, it may be moving through the hydrologic system, adsorbed on sediment particles.

The limestone rocks that compose the shallow aquifer in the basin have karst features, such as sinkholes, springs, and losing streams, indicating that water moves relatively freely between surface-water bodies and groundwater aquifers. Water movement in the shallow aquifer generally follows the topography. In upland areas, precipitation recharges the shallow aquifer, then the shallow-aquifer water discharges into larger streams; a noted exception is the downstream reach of Honey Creek, which loses as much as 5 million gallons per day to the subsurface. Dye injected into the losing reach of Honey Creek traveled a straight-line distance of 9 miles to Big Spring in about 7 days, indicating a conduit-type connection made possible by solution openings in the carbonate rocks.

At Verona, dye injected into the alluvial aquifer, near a former waste lagoon, traveled 2700 feet to the Spring River in about 50 days. The physical structure of the alluvium probably limits the travel of even the smallest sediment particles through the alluvium.

Sediment yields generally are small in the upstream part of the Spring River basin. Suspended-sediment discharges for the Spring River at La Russell ranged from 3.0 tons per day at a flow of 79 cubic feet per second, 1.7 times the 7-day 2-year low flow, to about 1240 tons per day at a flow of 1600 cubic feet per second, 6.7 times the long-term average. Suspended-sediment particles in the Spring River and Honey Creek generally were silt and clay (smaller than 0.062 millimeter). The streambed material generally is larger than silt. Fine sediments with adsorbed dioxin may be transported out of the area by stream-flow, or they may be deposited on flood plains or in downstream impoundments during periods of flooding.

Due to presence of solution openings in the limestone, the possibility that dioxin-contaminated fine sediments may be transported through them cannot be overlooked; however, during this study no water samples were collected from springs or wells, for dioxin determination. Such potential needs to be evaluated in future studies.

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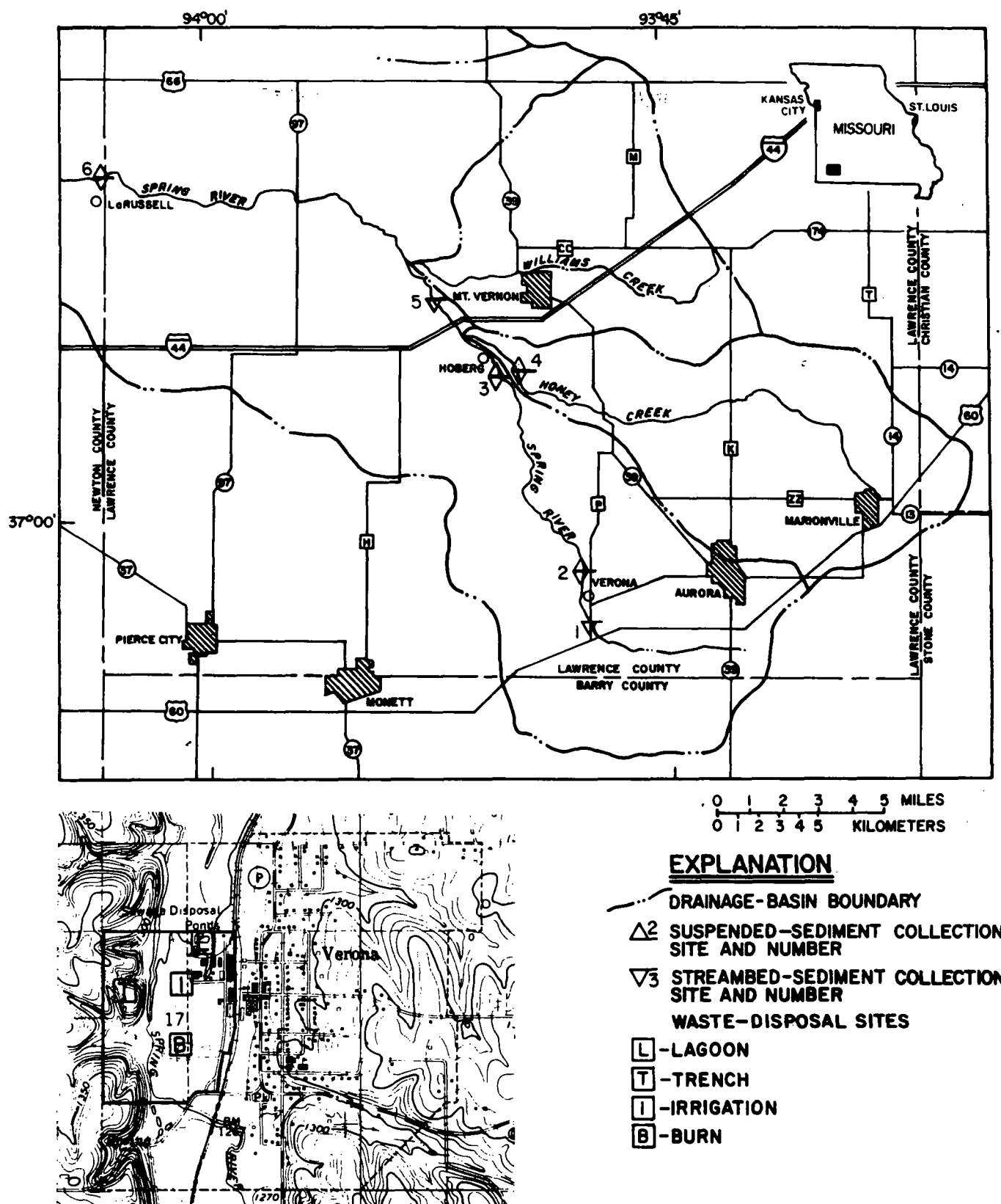


Figure 1. Location of the Spring River basin, upstream from La Russell, and sediment-collection sites.

CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below.

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
inch (in.)	25.40	millimeter (mm)
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /s)
mile (mi)	1.609	kilometer (km)
square mile (mi ²)	2.590	square kilometer (km ²)
gallon (gal)	3.785	liter (L)
gallon per minute (gpm)	0.06308	liter per second (L/s)
gallon per minute per foot (gpm/ft)	0.2070	liter per second per meter (L/s)/m
million gallons per day (mgd)	0.04381	cubic meter per second (m ³ /s)
pound avoir du pois (lb)	453.6	gram (g)
ton, short	0.9072	megagram (Mg)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, called NGVD of 1929, is referred to as sea level in this report.

GEOLOGY

The geology of the area was mapped on the 7½-minute Aurora, Chesapeake, Mt. Vernon, and Verona quadrangles (pls. 1-4). Discussion of the geology concentrates on Pennsylvanian and Mississippian units, because of their proximity to the land surface, hence, their susceptibility to surface pollution. The geologic formations and their hydrologic properties are summarized in table 1. Structural features and surface materials are important factors affecting groundwater movement and ground-water-surface-water relationships.

PENNSYLVANIAN SYSTEM

The youngest consolidated formations in the study area are Pennsylvanian, consisting of channel sands (sandstone) and deposits in filled sinkholes. The most extensive deposits of channel sands are in the Aurora quadrangle (pl. 1), where they strike north-northeast and have an average thickness of 150 ft and a maximum thickness of approximately 225 ft (Rutledge, 1929; Anderson, 1979). The maximum width of the major channel, the Aurora channel, is approximately 1.25 mi. These deposits are about 70 percent sand, 25 percent conglomerate, and 5 percent shale, with small quantities of large-grained gravelly sands in selected areas. Most of the sands contain iron and are stained either yellow with limonite or deep red with hematite. Fairly large deposits of goethite and hematite in the channel sands north and south of the study area were mined in the past. In many sands, the iron compounds are the cement binding the sand grains; in others, grains have quartz overgrowths, resulting in orthoquartzites in some areas.

The conglomeratic part of the channel deposits have angular to rounded chert fragments ranging from 0.25 in. to almost 1 ft in diameter. There are occasional slump blocks of limestone, as much as 6 to 8 ft in diameter and 2 to 5 ft thick, derived from the surrounding Mississippian bedrock.

Areal distribution of the channels are controlled by scour channels in the Mississippian terrain; some may have been eroded during the Late Mississippian. It is believed that at least some parts of the channels contain sediments of the Carterville Formation at the carbonate-conglomerate contact, indicating a Mississippian-Pennsylvanian age for those channels. The channels also are spatially controlled by structures such as faults, joints, and synclines in the Mississippian bedrock. Although the channels have been eroded into the Mississippian Burlington and Keokuk Limestones and Reeds Spring Formation near Aurora, farther north they have been eroded into older formations.

The small, Pennsylvanian-age Verona channel bears almost due east along the strike of the Ritchey fault, mainly on the downthrown side. Post-Pennsylvanian erosion has removed most of the channel-fill sands. The Verona channel contains no shale, and the conglomerates are fewer and finer textured than those in the Aurora channel.

Pennsylvanian sinkhole deposits, believed to be remnants of bedded Pennsylvanian sediments (totally removed in some cases), occur throughout the study area but are not

INTRODUCTION

During 1982 the U.S. Environmental Protection Agency, through an inter-agency agreement, requested the U.S. Geological Survey to make a hydrogeologic appraisal of the upstream part of the Spring River basin (fig. 1). The work was done jointly with the Missouri Department of Natural Resources, Division of Geology and Land Survey, to assist the U.S. Environmental Protection Agency in their study of dioxin contamination in an area associated with a chemical plant that had manufactured the herbicide Agent Orange, and the antiseptic, hexachlorophene. Manufacturing processes involved the intermediate production of 2,4,5-trichlorophenol and the resulting formation of the dioxin compound, TCDD (2,3,7,8-tetrachlorodibenzo-*p*-dioxin), hereafter referred to as dioxin. Most of the dioxin produced in the manufacture of Agent Orange remained as an impurity in the herbicide, but that produced in the manufacture of hexachlorophene became part of various waste products. Some of these wastes were transported to disposal facilities outside the manufacturing area; some were disposed at various locations in the upstream part of the Spring River basin, including, but not limited to, lagoon, trench, burn, and irrigation sites near Verona; a municipal dump at Baldwin Park in Aurora; and several surface sites on farms. Some of these sites have been reclaimed. According to information supplied by the U.S. Environmental Protection Agency (written communication, 1983) dioxin has contaminated soils, streambed materials, and fish tissue, in the upstream part of the Spring River basin. Soil samples analyzed by the U.S. Environmental Protection Agency indicate that dioxin and other hazardous substances are present in soils at the lagoon, trench, burn, and

irrigation waste-disposal sites on the chemical plant property (fig. 1).

The persistence of dioxin in the environment has been shown by several studies (Esposito and others, 1980). Dioxin is resistant to biodegradation. It may be photolytically degraded in the environment, but the extent of degradation has not been assessed. Dioxin is strongly sorbed on organic and inorganic sediments (U.S. Environmental Protection Agency, 1979).

Because of the extreme toxicity of dioxin, its transport in the environment is of critical concern. According to research summarized by Esposito and others (1980), dioxin applied to the land surface generally remains in the upper 6 to 12 in. of the soil zone. However, migration may occur to depths of 3 ft or more in sandy soils, particularly in areas that receive significant rainfall. Results of numerous studies support the belief that the vertical migration of dioxin is limited. Erosion and transport of dioxin-contaminated soil into streams and lakes, during runoff or flooding, or both, appear to be a primary mode of contamination. Water in contact with dioxin-contaminated soils for long periods may dissolve minute quantities of dioxin, but the reported solubility of the latter is very small: 0.2 $\mu\text{g/L}$ (U.S. Environmental Protection Agency, 1979).

PURPOSE AND SCOPE

The principal objectives of this study were to determine water movement and sediment characteristics of the area, so that the general movement of dioxin-contaminated wastes would be known if water and sediment proved to be the transport mediums. A secondary

shown on plates 1-4. Some sinkhole deposits contain Mississippian "Carterville"-type limestone boulders and chert fragments. Most contain shale and fine sand, which grade upward into slightly coarser sand. The distribution of the sinkhole deposits are best shown on an early map by Rutledge (1929).

MISSISSIPPIAN SYSTEM

The youngest Mississippian unit in the study area, the Carterville Formation, is present only in the Aurora quadrangle, in secs. 7, 8, and 18, T. 26 N., R. 25 W. Some confusion exists in the use of the term "Carterville." As defined in *The Stratigraphic Succession in Missouri* (Howe and Koenig, 1961), and as applied by the mining industry in the Tri-State Mining District, the Carterville is a residual formation comprising coarse sandstone, conglomerate, limestone, and shale occurring in sinkholes and other paleokarst features and reported to be as much as 200 ft thick.

A few remnants of the Warsaw Formation are present about 2 mi northwest of Mt. Vernon and along the Ritchey fault west of Verona. The Warsaw is a light-gray to white, dense, coarse-grained, oolitic limestone with some chert. The thickness is unknown but is believed to be less than 40 ft.

The Burlington and Keokuk Limestones were mapped as one unit, the Burlington-Keokuk Limestone, because of their lithologic similarities. Their combined thickness ranges from 0 to 200 ft. As a unit, the Burlington-Keokuk is mainly a dense, coarse-grained, massive-bedded, light-gray to brown limestone. Most residual cherts in the soil mantle originated from the Burlington-Keokuk Limestone, the chert content of which averages about 30 to 40 percent. The

lower part may contain less than 10 percent chert. Deeply weathered joints and paleokarst features are present in the Burlington-Keokuk Limestone. Although not always easy to document, it is believed that most of the surface-drainage system is controlled by the joint system in the Burlington Keokuk.

The Elsey Formation, averaging approximately 30 ft thick, lies beneath the Burlington, on the Reeds Spring Formation. The Elsey is a cherty gray to gray-brown, dense, somewhat oolitic limestone with a chert content of 60 to 90 percent. Large solution openings have developed along the contact between bedded cherts in the Elsey and the enclosing limestone. Solution in many places has removed all the limestone, leaving thick porous intervals of bedded chert. The Elsey chert, readily identifiable in the soil zone, is blue gray to light brown, with small gray specks, and has a smooth porcelain-like texture.

Beneath the Elsey, the Reeds Spring Formation intertongues with the underlying "Fern Glen Formation" and is 0 to 200 ft thick in the study area. The chert, which averages 40 percent of the formation, is mostly blue, gray, and brown, with a smooth porcelain to quartzose texture. The upper 30 to 40 ft of the formation is a dark, gray-blue to maroon fine-grained limestone. The Reeds Spring forms many of the bluffs along the Spring River near Verona.

Although the Fern Glen is not presently recognized as a formation in Southwest Missouri, most older literature and well logs refer to it as a distinct unit. Present-day workers include Fern Glen-type lithology in the Pierson Formation but do not use the term Fern Glen. For convenience, however, and to avoid confusing other workers searching through old mining

CHARACTERISTICS OF THE SPRING RIVER

objective was to prepare a detailed description of the geology, especially the geohydrology, of the area.

The approach to the work included an onsite inventory of wells in the shallow (Mississippian) aquifer and deep (Ordovician and Cambrian) aquifer, and preparation of maps depicting groundwater levels and direction of groundwater movement. Gaining and losing reaches of streams were identified by seepage runs and aerial observations. Dye-tracer studies were used to determine further the hydraulic connection between surface- and groundwater systems and identify areas where groundwater discharges as major springs. Suspended-sediment samples were collected at four sites during various flow conditions and analyzed for concentration and particle size. Streambed samples were collected at six sites and analyzed for particle size and dioxin.

DESCRIPTION OF THE STUDY AREA

The study area (fig. 1) includes the Spring River basin upstream from La Russell, a drainage area of 306 mi². The area is on the Springfield Plateau, which is underlain by rocks of Mississippian age. Sinkholes, springs, and losing streams occur throughout much of the area. The terrain is slightly rolling in the divide areas, with moderate relief near the streams. Elevations range from 1020 to more than 1500 ft.

Most of the study area is in Lawrence County. Aurora, with a population of 5400, is the largest city in the area. Mt. Vernon located near the confluence of Spring River and Honey Creek, has a population of 2600. Verona, population 500, is on the east side of the Spring River, in south-central Lawrence County.

PREVIOUS WORK

Feder and others (1969) appraised the water resources of the Joplin area, including the Spring River basin. Gann and others (1974) prepared a general summary of information concerning occurrence, availability, and use of water in an 18,000-mi² area of western Missouri, including the Spring River basin. Although specific information about the upstream part of the Spring River basin is limited, both reports contain excellent descriptions of the regional geological and hydrological setting.

The U.S. Geological Survey operated a streamflow-gaging station on the Spring River, at La Russell, Missouri, from April 1957 to December 1981. Records for this station are published in the U.S. Geological Survey annual reports *Water Resources Data for Missouri*.

During 1971 the Missouri Division of Geology and Land Survey investigated unlined lagoons as part of the chemical plant waste-disposal procedures, in the Spring River alluvium. Between 1971 and 1979, infrequent onsite investigations and inspections were made in connection with plant operations and organic-compound pollution problems. During 1979 the U.S. Environmental Protection Agency confirmed the presence of waste deposits containing dioxin at several sites in and around Verona. Subsequently, the U.S. Environmental Protection Agency, the Missouri Division of Geology and Land Survey, and the Missouri Department of Conservation have made exhaustive efforts to determine the locations and extent of dioxin contamination. Cleanups and monitoring have been done by the U.S. Environmental Protection Agency or the chemical plant, or both, at selected sites. Information about these activities are available from the respective parties.

across the Verona-Aurora quadrangles. Like the Chesapeake fault, it has not been active since the Mississippian. Most movement on it has been vertical; displacement has been less than 150 ft. The fault trace is characterized by remnants of channel sands. As much as 2.5 mi west of Verona, a silicified fault breccia can be observed in many places along the fault. Geologic evidence south and southeast of Verona suggests the Ritchey fault extends at least 6 mi east of previously mapped locations (pls. 1 and 4). It is not known to what depth the fault breccia extends, but it is possible that it may restrict lateral groundwater movement if silicified to an appreciable depth.

McCracken (1971), following Thiel (1924), describes the Verona anticline " . . . as a broad, low anticlinal structure near Verona with the crest passing southeastward, east of Catton Mill and McDowell, and passing through Hurley and Shell Knob, then crossing White River through Viola to Arkansas. The structure appears to be plunging northwest, dying out in Lawrence County, Missouri." There are insufficient data to establish whether the Verona anticline is offset by the Ritchey fault or the fault has undergone readjustment due to development of the Verona anticline.

SURFICIAL MATERIAL

As used in this report, *surficial material*, or *soil*, refers to all unconsolidated material overlying bedrock and is not used in the agricultural sense. Cherty red clay, characteristic of the Ozarks, is the dominant surficial material in the Verona-Aurora area. Flood plain and other alluvial deposits consist of silty loam a few feet thick, underlain by gravel. Physical properties of surficial

material vary depending on parent material and topography. The thickness of the various types of surficial material in the Verona-Aurora area ranges from 5 to 60 ft.

Surficial material on the slightly to moderately rolling upland terrain is a residuum developed from the weathering of limestone and some sandstone bedrock; that derived from limestone bedrock ranges from stone-free red clay to a cherty red clay. Chert fragments are the major constituent in some areas. Characteristically, the red clay is not dense unless chert fragments are abundant. Clay structure is angular and blocky, and the clay is somewhat plastic. Permeability, as determined in the laboratory, ranged from 2.8×10^{-4} to 2.8×10^{-5} ft/d. Onsite permeability is assumed to be much greater, however, because discrete flow can occur along the more cherty zones in the soil as well as along the faces of the soil peds of the red clay.

Topographic relief is a significant factor affecting sorting and other properties of the residuum. Residuum on the slightly rolling to almost level uplands, where sorting is not significantly affected by gravity, has the relict structure of the parent bedrock. It is commonly observed that relict chert beds from the limestone bedrock persist laterally into the cherty clay residuum. Where this type of surficial material exists, gross permeability is greater than where there is a poorly sorted mixture of chert fragments within the clay matrix of the residuum.

On the moderately rolling terrain, the surficial material tends to be poorly sorted. Although permeability may still be large, the rate and magnitude of recharge tend to be somewhat slower and smaller compared with residuum on the gentle uplands. Residual surficial

TABLE 1

Generalized section of geologic formations and their hydrologic properties in the Lawrence County area, Missouri
(The stratigraphic nomenclature generally follows that of the U.S. Geological Survey and the Missouri Division of Geology and Land Survey; however, there are some variations from the current usage of the U.S. Geological Survey)

System	Series	Stratigraphic unit	Thickness, in.ft.	Physical characteristics	Depth to top of formation, ft	Water-bearing characteristics	
QUATERNARY	Recent	Alluvium and upland soil	5-60	Alluvium and upland soil	Outcrop	Yields small supplies for domestic and stock use	
	Undifferentiated	Undifferentiated	0-225	Sandstone and conglomerate with lesser quantities of shale and iron	Outcrop	Yields little water to shallow dug wells	
MISSISSIPPIAN	Chesterian	Cartersville Formation	0-200	Limestone, shale, siltstone, and sandstone, generally found filling depressions in underlying rocks	Outcrop to 10	Does not yield water to wells	
		Warsaw Formation	0-40	Dense coarse grained limestone, somewhat dolitic	Outcrop	Yields little water except in isolated solution channels	
	Osagean	Burlington Keokuk Limestones	0-200	Dense cherty limestone, sometimes mineralized with zinc and lead	Outcrop to 50	Shallow aquifers	Yields little water where massive, but can yield more than 100 gallons per minute in fractured areas. Solution channels may yield large supplies
		Elsay Formation	0-45	Fine grained, very cherty limestone, sometimes all chert and mineralized with zinc and lead	Outcrop to 200		Generally yields adequate supply for domestic and stock use, rarely more than 50 gallons per minute. Supplies many springs
		Reeds Spring Formation	0-200	Dark, very cherty, argillaceous limestone, sometimes mineralized with zinc and lead	Outcrop to 250		Generally yields adequate domestic or stock supply. Supplies many springs
		"Fern Glen Formation"	0-35	Limestone, fine to coarse grained, fossiliferous, and somewhat cherty	275	Yields very small quantities of water	
		Person Formation	0-10	Cherty limestone, some silt and sand present	Outcrop to 300	Yields very small quantities of water	
	Kinderhookian	Northview Formation	0-15	Shale or shaly limestone, absent in portions of area; may be silty	Outcrop to 310	Confining bed	
		Compton Formation	0-30	Limestone, fine to coarse grained, fossiliferous, and somewhat cherty	Outcrop to 325	Generally does not yield water	
	ORDOVICIAN	Lower	Cotter Dolomite	150-275	Cherty dolomite, some sandstone beds	Outcrop to 300	Deep Aquifers
Jefferson City Dolomite			220	Cherty dolomite	100-550	Yields small quantities of water	
Roubidoux Formation			150	Cherty dolomite and several sandstone beds	600-750	Generally yields between 50-100 gallons per minute.	
Gasconade Dolomite			320	Cherty dolomite, sandstone bed at base of formation	750-900	Yields small supplies of water	
CAMBRIAN	Upper	Eminence and Potosi Dolomites	300	Dolomite with drusy chert in lower 50 feet.	1050-1200	Generally yields between 50-400 gallons per minute, especially from lower part	
		Derby Doerun Dolomites, Davis and Bonnetiere Formations undifferentiated	400	Silty dolomite, some siltstone and shale	1360-1415	Yields small quantities of water.	
		Lancette-Beagan Sandstone	200	Quartzite sandstone to sandy, silty, shaly dolomite	1600-1800	Yields vary considerably. Formation may be absent over Precambrian highs	
PRECAMBRIAN		Basement complex		Granite and rhyolite	1900-2000	Generally does not yield water	

AURORA ABANDONED MINE AREA

Most lead and zinc mining in the Aurora area was in the Mississippian bedrock, at depths of 120 to 170 ft, and to a lesser extent, in the residuum, at depths of 20 to 80 ft. Mississippian formations mined were the Burlington, Elsey, Reeds Spring, and "Fern Glen," mostly the Elsey and Reeds Spring. At 500 ft, the deepest mines were in the Ordovician Cotter Dolomite. Roof stability could not be maintained in some shallow mines, and roofs collapsed leaving large water-filled subsidence areas at the surface, many of which have been filled. The principal areas of subsidence are in secs. 5, 6, 7, 8, 17, and 18, T. 26 N., R. 25 W. The location of all the shafts known to have existed in the Aurora area between 1886 and 1982 are shown in plate 5.

Mining left many underground openings, as much as 1.5 mi long and usually less than 100 ft wide, that trend along breccia-filled karst tubes and solution-enlarged joints (pl. 6). The joints commonly are filled with clay and breccia in the shallow subsurface, and with breccia and water at deeper levels. In places the cement in the breccia is secondary calcium carbonate or silica. Blocks and fragments in the matrix are reworked and broken limestone and chert. All combinations of matrix and rock types are present.

Although some of the filled karst tubes are relatively impermeable, many are very permeable and open, producing as much as 2000 gpm of water. During the active mining period, excessive water was a major engineering problem. Records indicate most of the water was from the Elsey Formation, at about the 170-ft level.

Mining records indicate that the karst tubes are connected with filled-

sinkhole deposits on the surface. The deposits are Mississippian Carterville sandstone and limestone, and Pennsylvanian shale and sandstone. The major sinkhole deposits are shown on the underground mine map (pl. 6). Some mines penetrated the Ordovician Cotter Dolomite and the Pennsylvanian channel sands. Water production from them was considered minimal.

The reasons for the high static water levels in the mine area are not completely understood, but it is possible to find water flowing from old mine workings that have been filled, leveled, and converted to pastures, as well as from those still open. Workers who filled some of the old mine shafts told the authors that soil, clay, and any kind of fine-grained material put into the shafts were commonly washed out onto the surface within a few hours.

Although it is not possible to document specific reasons for the high static water levels, several geologic conditions in the vicinity of the mines are believed to relate to the somewhat anomalous local high water table. The Pennsylvanian channel sandstone on the east side of the mining area may be capable of storing seasonal recharge and releasing it to the limestone over a longer time, thus maintaining the water table at a higher level.

The Ritchey fault zone may be silicified to great depths and may extend farther eastward than is shown on the geologic map (pl. 1). Silicified rock in the fault zone typically has little permeability. Similar zones of little permeability may exist at critical locations to the north, and they may compartmentalize the groundwater in the mine area.

records and well-logs, "Fern Glen Formation" is used informally in this report. As used herein, the "Fern Glen Formation" is a fine- to coarse-grained red, pink, to slightly greenish limestone that generally contains much less chert than the overlying formations. It is present in the subsurface in much of the study area but does not crop out therein.

The Pierson Formation is present in much of the subsurface and crops out in the areas adjacent to the study area. Well logs indicate a few feet of Pierson in the general Aurora-Verona area. The Pierson and the "Fern Glen" are lithologically similar in this area, making it difficult to distinguish between them. In most other localities, the Pierson is a fine- to medium-grained brown dolomite, or dolomitic limestone; in the study area, it is a fine- to medium-grained crystalline limestone containing chert and some fine sand and silt.

The Northview Formation, underlying the "Fern Glen" or Pierson, varies from a green-gray silty limestone to a green to brown shale and averages about 10 ft thick. The porosity varies markedly, depending on the proportions of the indicated lithologies.

The oldest Mississippian unit, the Compton Formation, is 0 to 30 ft thick but averages 20 ft. It is a somewhat cherty light-gray to greenish-gray limestone, with green shale partings in places; fine sand occurs in a few places. The porosity is low. The Compton is underlain unconformably by the Cotter Dolomite.

ORDOVICIAN AND CAMBRIAN SYSTEMS

The Ordovician and Cambrian Systems are not described in detail because they are comparatively deep in

the subsurface; they are of interest primarily as an aquifer.

The Ordovician System, approximately 850 ft thick, comprises light-gray-brown cherty sandy fine-grained dolomites with a few thin shale layers. The Cotter Dolomite crops out southwest of the Chesapeake fault, in the Chesapeake quadrangle, north of Aurora.

The Upper Cambrian section, approximately 900 ft thick, comprises gray-brown fine-grained dolomites to very coarse-grained crystalline dolomites and small quantities of limestone. Generally, the Cambrian rocks have much less chert and more shale and silt than the Ordovician rocks.

STRUCTURE

The most important structures in the study area are the Chesapeake fault, the Ritchey fault, the Verona anticline (pls. 1-4), and the many deeply weathered joints. The Chesapeake fault, a normal fault with displacement of less than 125 ft, strikes northwest across the northwest part of the Chesapeake quadrangle and is traceable into eastern Kansas. The Ordovician Cotter Dolomite, on the southwest fault block, is in contact with the Mississippian Burlington-Keokuk Limestone, on the northeast (downthrown) fault block. During the Pennsylvanian, the Chesapeake fault escarpment affected the deposition of the channel sands. Just north of the confluence of the Aurora and Billings channels, the Aurora channel is on the downthrown side of the fault. There is no indication of fault movement since the Mississippian.

The Ritchey fault, a normal fault through most of its trace, is a major structural feature trending N. 90 E.

Based on the described geologic setting, if dioxin or other hazardous wastes exist within the Aurora mined area, extensive lateral movement in the regional aquifer would be unlikely, because water movement would be near, or perhaps on, the surface. It is apparent that an extensive paleokarst exists in the Aurora mined area, but it is not known to what degree there is connection between the Pennsylvanian-Mississippian aquifer and the Ordovician-Cambrian aquifer as a result of solution activity.

Surface disturbances resulting from mining operations include pits, mine shafts, mills, tailings piles, mounds, and dumps. The area of ground disturbances (fig. 2) was plotted from aerial photographs made in 1939 and 1967. They also were used to verify the information in

plates 5 and 6. Much of the disturbed ground identified on the 1939 photographs was not observed on the 1967 photographs, because of intervening land-use changes. Undoubtedly, additional changes have occurred since the 1967 photographs were taken. For example, many areas have been reclaimed for recreation and agricultural purposes.

The components of the disturbed ground range in size from finely crushed, silt-size limestone and chert to angular blocks of limestone and chert 3 ft or more in diameter. Much sand is present locally where mine operations penetrated the Cartersville Formation or the Pennsylvanian channel sands. The thickness of these materials ranges from a few inches, to more than 100 ft where pits have been backfilled.

WATER MOVEMENT

GROUNDWATER

Major aquifers in the study area include the shallow aquifer in Mississippian cherty limestone and the deep aquifer in Ordovician and Cambrian cherty dolomite and sandstone (table 1). The shallow and deep aquifers are separated by a confining bed of Mississippian silty limestone and shale. The relative locations of the shallow and deep aquifers and the confining bed, and the altitudes of the respective potentiometric surfaces are shown on the hydrologic sections in figures 3 and 4. Sections A-A' and B-B' are on plate 7.

Shallow Aquifer

In places, the shallow aquifer extends to depths as much as 410 ft from the surface. Because of generally smaller

yields and water of poorer quality than the deep aquifer, the shallow aquifer is mainly limited to domestic use. In Lawrence County, wells completed in the Mississippian limestone generally yield as much as 45 gpm and average approximately 12 gpm (Harvey and Emmett, 1980). Brecciated areas generally are the most permeable, whereas surrounding dense limestones have little permeability. The presence of fractures and solution openings that allow significant secondary permeability greatly increases availability and movement of groundwater.

A potentiometric map of the shallow aquifer (pl. 7) was prepared from water levels measured in about 100 wells ranging from 10 to 400 ft in depth. The

CHARACTERISTICS OF THE SPRING RIVER

material 30 to 60 ft. thick has formed along a generally north to northwesterly trend, in the middle part of the area, along the broad anticlinal structure (Verona anticline) described in the *Structure* section of this report. Thicker surficial materials are common along the crests of anticlines in limestones or dolomites, rock characterized by more intense joint development and thus more subject to development of solution openings.

Sandstone is much more resistant to weathering than limestone; hence, residual soil or surficial material developed on sandstone is thin. The most extensive such deposit is the north-trending one developed on sandstone, in the eastern part of the area. The soil thereof is a sandy clay to sandy loam, 2 ft to perhaps as much as 10 ft thick.

The gross permeability of residual soil on sandstone is relatively small compared with that of residual cherty clay developed on limestone. Slow, diffuse, rather than more rapid, discrete, water movement occurs in the former; therefore, meteoric-water recharge to bedrock is much less in the sandstone outcrop areas.

Loess, fine-grained windblown material, occurs on the more gentle uplands in the area. A silty loam or silty clay, loess covers the residual surficial material developed on limestone and sandstone. A fragipan, commonly called "hardpan," a high-density, low-permeability soil layer, generally exists in the lower part of the loess deposit. The total thickness of loess and fragipan may be as much as 4 ft. Both loess and fragipan, but especially the latter, retard downward movement of infiltrating water, tending to offset to some extent the greater recharge properties of the residuum on the gentle

uplands. However, where upland drainages have eroded through loess and fragipan, losing streams are common.

Alluvium on the larger flood plains, such as that along Spring River or Honey Creek, is relatively consistent in physical properties and thickness. The upper few feet vary from silty loam to very silty clay; the remainder is predominantly gravel, with varying quantities of sand, silt, and clay. The total thickness ranges from 10 to as much as 30 ft. The alluvium is permeable, but rates of flow depend on losing or gaining streamflow conditions. Groundwater movement is relatively slow in the gaining reach of Spring River, as determined from a dye-tracer study described in the *Dye-Tracer Studies* section of this report. Flow rates are much greater in losing reaches, as indicated by a dye-tracer study in Honey Creek. However, in the losing reaches, it is difficult to distinguish flow rates in the coarse, poorly sorted gravels, from those in bedrock openings beneath or adjoining the channel of losing stream reaches, in which the subsurface rapidly receives large quantities of surface runoff until the voids in the alluvium and bedrock are water filled. Thus, the potential effect of pollutants in losing stream reaches generally is much more serious and rapid than in gaining stream reaches.

In summary, surficial material in the Verona-Aurora area is generally typical of residual and alluvial materials developed in the Ozarks. Nevertheless, more surficial materials common to losing streams exist in the study area than commonly occur in a typical Ozark setting. The thin sandy soil and associated sandstone bedrock in the area also appear to be anomalous with respect to usual Ozark conditions.

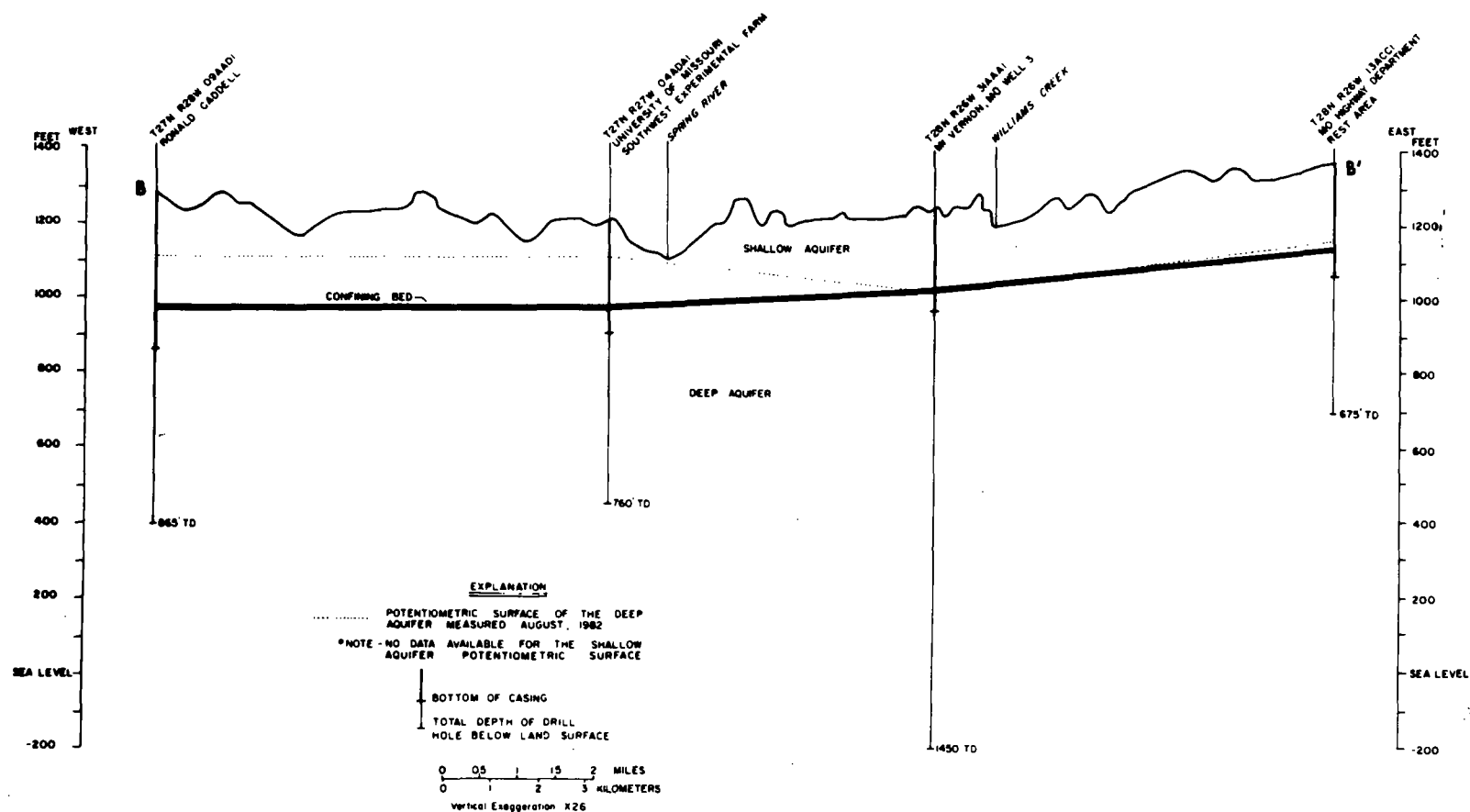


Figure 4. Hydrologic section B-B' (west-east), across northern Lawrence County (see pl. 7 for section location).

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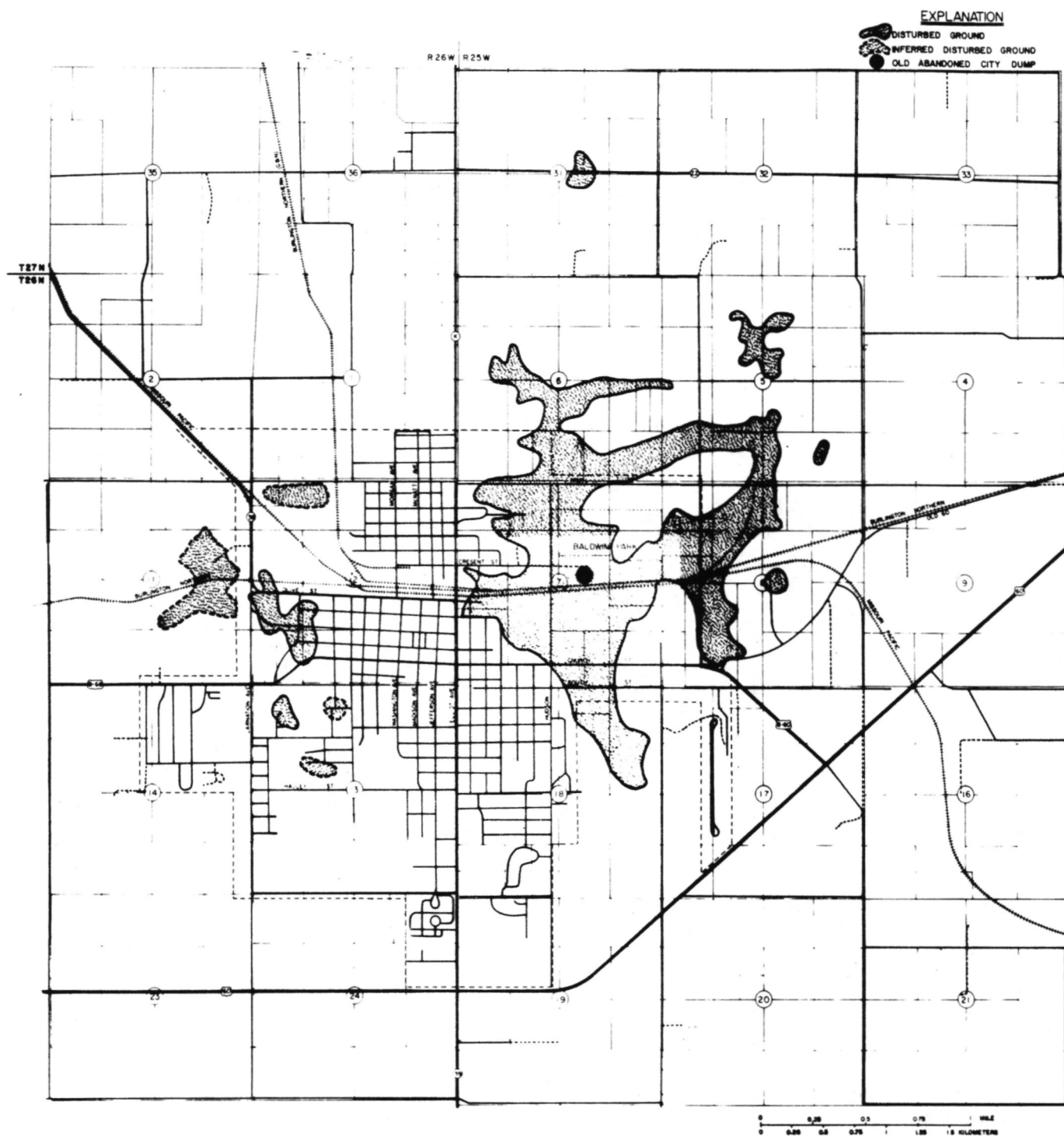


Figure 2. Location of ground disturbed by mining in the Aurora area.

Movement of water in the deep aquifer coincides with the regional topographic slope to the northwest but is not affected by local changes in topography.

SURFACE WATER

Spring River begins about 5 river mi southeast of Verona, flows northwest past Mt. Vernon, west into Kansas, then south into Grand Lake of the Cherokees in Oklahoma, a distance of about 120 river mi. The drainage area at La Russell (fig. 1), which is at the downstream end of the study area, is 306 mi². Honey Creek, with a drainage area of about 66 mi², begins near Aurora and flows west about 21 river mi before entering Spring River. The average daily discharge for Spring River at La Russell,

from April 1957 to December 1981, was 243 ft³/s; the minimum, 15 ft³/s; and the maximum, 22,500 ft³/s. Maximum instantaneous, minimum instantaneous, and mean annual discharges for the Spring River at La Russell (water years 1970-81) are listed in table 3.

Numerous springs are in the upstream part of the Spring River. Big Spring, the largest, emerges from the base of a high bluff of Keokuk Limestone, near the mouth of Williams Creek, 3 mi northwest of Mt. Vernon. During low-flow conditions, Big Spring discharges about 15 to 25 ft³/s, about half the flow in the Spring River immediately downstream from Williams Creek.

During early November 1982, a seepage run was made in the upper

TABLE 3

Maximum instantaneous, minimum instantaneous, and annual mean discharges for the Spring River at La Russell, water years 1970-81

Water year ¹	Discharges, in cubic feet per second		Annual mean
	Maximum instantaneous	Minimum instantaneous	
1970	5,510 (May 1)	17 (Jan. 8)	149
1971	18,000 (Sept. 6)	30 (Sept. 4, 5)	216
1972	2,760 (Dec. 15)	23 (Aug. 20)	138
1973	22,500 (Nov. 1)	64 (Sept. 22)	590
1974	15,500 (Nov. 25)	104 (Sept. 30)	556
1975	8,120 (Nov. 4)	73 (Oct. 11, 12)	431
1976	11,700 (July 4)	54 (Nov. 28)	218
1977	3,460 (Sept. 29)	16 (June 17)	111
1978	6,470 (Mar. 24)	78 (Sept. 29, 30)	336
1979	19,800 (May 20)	33 (Jan. 15)	352
1980	1,880 (Mar. 30)	30 (several days)	162
1981	4,860 (June 11)	28 (Feb. 12)	137

(discontinued)

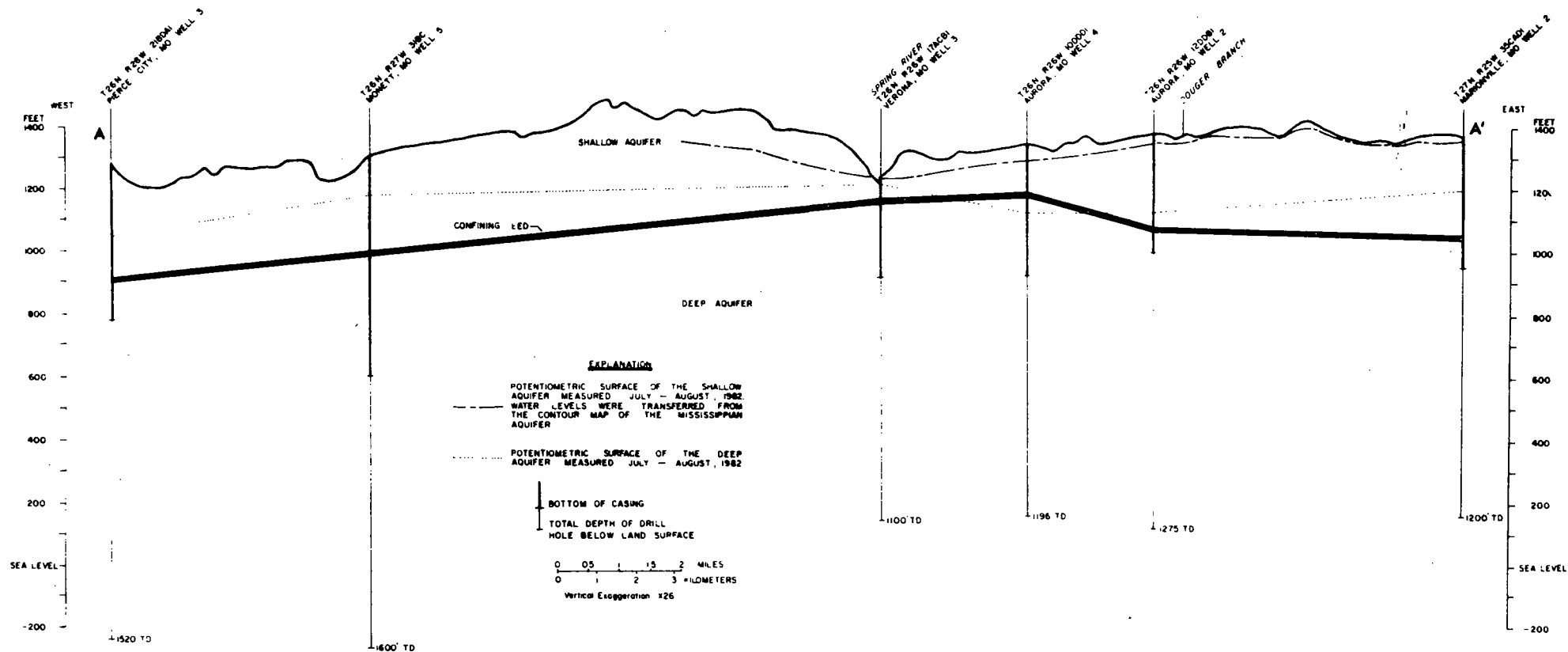


Figure 3. Hydrologic section A-A' (west-east), across southern Lawrence County (see pl. 7 for section location).

TABLE 4
Low-flow data for streams and springs

Map no. (fig. 5)	Station name	Location	Date	Discharge, (ft ³ /s)	Specific conductance (micromhos)	Water temperature (degrees Celsius)	7-day low-flow in ft ³ /s, for indicated recurrence interval, in years	
							2	10
1	Spring River	On line between secs. 21 and 28, T. 26 N., R. 26 W., at county road ford, 1 mi southeast of Verona	11-4-64	0	---	---	0	0
			7-15-82	0 (pools)	---	---		
			11-1-82	0 (pools)	---	---		
2	Spring River ¹	SE¼ sec. 20, T. 26 N., R. 26 W., at U.S. Highway 60 underpass, .5 mi south of Verona	7-15-82	8.0	330	16.5	5.0	3.0
			11-1-82	9.9	360	16.0		
3	Browning Hollow	SE¼ sec. 19, T. 26 N., R. 26 W., at county road ford, 1 mi south- west of Verona	7-15-82	0 (pools)	---	---	0	0
			11-1-82	0 (pools)	---	---		
4	Spring River	SW¼ sec. 17, T. 26 N., R. 26 W., at county road bridge in Verona	11-1-82	10.2	350	17.0	5.0	3.0
5	Unnamed Spring	SE¼ sec. 8, T. 26 N., R. 26 W., at culvert on County Highway P, 0.25 mi north of Verona	7-15-82	0.4	350	17.0	---	---
			11-1-82	.3	360	20.0		
6	Spring River	NE¼ SW¼ sec. 8, T. 26 N., R. 26 W., at county road bridge, 0.25 mi north of Verona	11-4-64	3.3	400	15.0	4.0	---
			7-15-82	9.0	320	17.0		
			11-1-82	9.4	350	18.0		
7	Chat Creek	NW¼ sec. 7, T. 26 N., R. 25 W., at bridge on County Highway K, in Aurora	7-15-82	0.1	---	---	---	---
			11-1-82	.1	600	18.0		
8	Chat Creek	On line between secs. 11 and 12, T. 26 N., R. 26 W., at bridge on State Highway 39 at Aurora	7-15-82	0 (pools)	550	21.5	0	0
			11-1-82	0 (pools)	---	---		

¹Flow at this site is outflow from Spring River Spring, located in NW¼ sec. 28, T. 26 N., R. 26 W

map shows the altitude of the water table, the slope and direction of groundwater movement, and the water-table location relative to streams.

Measured water levels ranged from 10 to 50 ft below land surface. Hydrologic divides generally correspond to topographic divides, and movement of groundwater is from the divide areas to streams. Spring River and the upstream part of Honey Creek are hydraulically connected to the shallow aquifer and generally are drains, although locally they may lose flow. The potentiometric map indicates that the water table is below the streambed in the downstream reach of Honey Creek. A seepage run and a dye-tracer study, as described in the *Surface Water and Dye-Tracer Studies* sections of the report, confirm that Honey Creek loses large quantities of water locally to the shallow aquifer. Water in the shallow aquifer does not appear to cross the regional basin divide, except possibly east of Aurora. The highest water levels coincide with the topographic highs just east of Aurora. Regional movement of water in the shallow aquifer is to the northwest.

Deep Aquifer

The deep aquifer, reached at a minimum depth of about 100 ft but extending as deep as 1900 ft, is used for municipal and industrial purposes, because it yields larger quantities and higher quality water than the shallow aquifer. Yields from eight municipal wells in the general area ranged from 300 to 600 gpm; specific capacities, from 1.9 to 7.1 gpm/ft (table 2). The primary source of the water is the Springfield-Salem Plateau area, as discussed by Harvey (1980).

A potentiometric map of the deep aquifer (pl. 8) was prepared from water levels measured in about 60 widely spaced wells ranging from 700 to 1700 ft in depth. The water levels ranged from 150 to 300 ft below land surface and were about 50 to 175 ft lower than water levels in the shallow aquifer. Vertical movement of water from the shallow to the deep aquifer is extremely slow, as indicated by a vertical hydraulic conductivity of 5×10^{-10} ft/s computed by Harvey and Emmett (1980) for the confining bed near the study area.

TABLE 2

Yields and specific capacities for selected municipal wells in Lawrence County

Well name	Yield (gpm)	Specific capacity
Verona No. 3	400	6.25
Aurora No. 4	520	7.12
Aurora No. 1	350	6.03
Aurora No. 2	350	5.83
Pierce City No. 3	600	3.33
Pierce City No. 2	320	4.64
Mt. Vernon No. 3	500	1.90
Mt. Vernon No. 2	300	4.00

TABLE 4 (continued)

Map no. (fig. 5)	Station name	Location	Date	Discharge, (ft ³ /s)	Specific conductance (micromhos)	Water temperature (degrees Celsius)	7-day low-flow in ft ³ /s, for indicated recurrence interval, in years	
							2	10
17	Honey Creek	On line between secs. 22 and 27, T. 27 N., R. 25 W., at county road bridge downstream from sewage lagoons, 1 mi northwest of Marionville	11-1-82	0.2	660	18.5	--	--
18	Honey Creek	NE¼ sec. 21, T. 27 N., R. 25 W., at county road bridge, 1 mi downstream from Polk Spring and 2 mi northwest of Marion- ville	11-2-82	6.5	400	15.5	4.0	2.0
19	Honey Creek	SE¼ NE¼ sec. 13, T. 27 N., R. 26 W., at bridge on County High- way K, 4 mi north of Aurora	11-4-64	4.8	360	14.5	5.0	2.5
20	Elm Branch	On line between secs. 23 and 24, T. 27 N., R. 26 W., at county road bridge, 3.5 mi northwest of Aurora	11-2-82	0	--	--	0	0
21	Honey Creek	SW¼ sec. 16, T. 27 N., R. 26 W., at bridge on State Highway 39, 3.5 mi southeast of Mount Vernon	11-4-64	3.6	350	16.5	--	--
			11-2-82	4.4	390	16.0	--	--
22	Honey Creek	NE¼ sec. 18, T. 27 N., R. 26 W., at county road bridge, 2.5 mi south of Mount Vernon	11-2-82	3.0	370	16.0	--	--
23	Honey Creek	SE¼ sec. 12, T. 27 N., R. 27 W., at county road bridge, 1.5 mi southeast of Hoberg	11-4-64	0.2	320	16.0	--	--
			11-2-82	2.2	350	16.5	--	--

CHARACTERISTICS OF THE SPRING RIVER

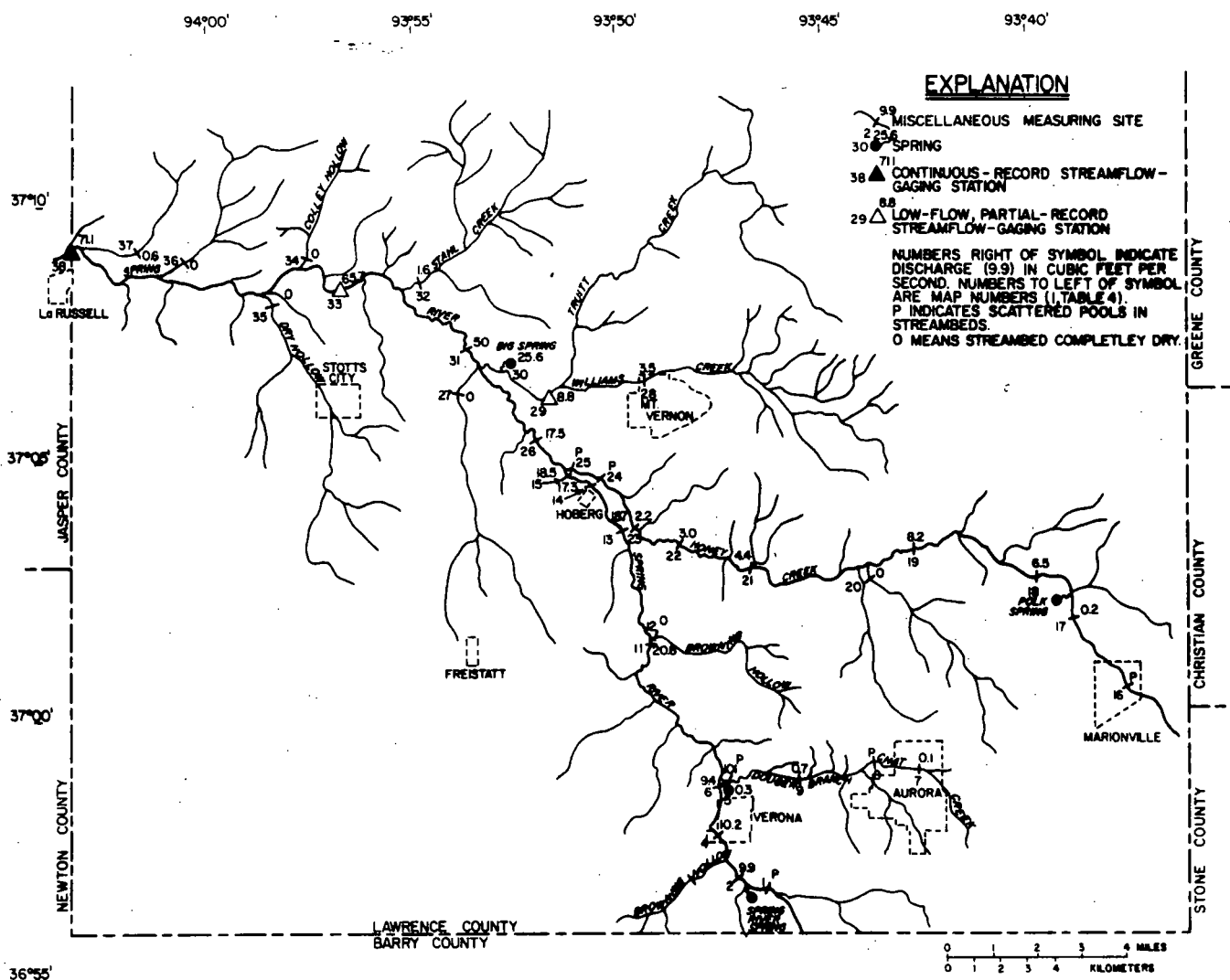


Figure 5. Measuring sites and seepage-run data in the upstream part of the Spring River basin, November 1-3, 1982.

Spring River basin (fig. 5). During 3 days, measurements of discharge, specific conductance, and water temperature were made at 38 sites on the Spring River and its tributaries upstream from La Russell (table 4). Measurements made during the seepage run were used to determine the magnitude and distribution of low flows, estimate low-flow frequency data at all possible sites, locate streams and stream reaches where surface flow is lost to

aquifers, and provide data used in study of groundwater-surface-water relationships in the area.

The low-flow frequency data shown in table 4 were computed using methods described by Skelton (1976), which provide reliable estimates of the 2-year recurrence-interval flows and less reliable estimates for the 10-year recurrence interval. However, there is no way to evaluate mathematically the

TABLE 4 (continued)

Map no. (fig. 5)	Station name	Location	Date	Discharge, (ft ³ /s)	Specific conductance (micromhos)	Water temperature (degrees Celsius)	7-day low-flow in ft ³ /s, for indicated recurrence interval, in years	
							2	10
32	Stahl Creek	NE¼ SE¼ sec. 18, T. 28 N., R. 27 W., at county road ford, 2.5 mi northeast of Stotts City	11-3-82	1.6	340	13.0	---	---
33	Spring River ²	On line between secs. 13 and 14, T. 28 N., R. 28 W., at bridge on State Highway 97, 2 mi north of Stotts City	11-4-64	30.6	340	16.5	42	19
			11-3-82	65.7	370	13.0		
34	Colley Hollow	On line between secs. 11 and 14, T. 28 N., R. 28 W., at county road ford, 3 mi north of Stotts City	7-14-82	0	---	---	0	0
			11-3-82	0	---	---		
35	Dry Hollow	SE¼ sec. 15, T. 28 N., R. 28 W., at county highway bridge, 2.5 mi northwest of Stotts City	7-14-82	0	---	---	0	0
			11-3-82	0	---	---		
36	Unnamed Creek	NW¼ NE¼ sec. 17, T. 28 N., R. 28 W., at county road ford, 3 mi east of La Russell	7-14-82	0	---	---	0	0
			11-3-82	0	---	---		
37	Unnamed Creek	SW¼ sec. 7, T. 28 N., R. 28 W., at county road ford, 1.5 mi east of La Russell	7-14-82	1.0	---	---	---	---
			11-3-82	0.6	380	12.0		
38	Spring River ⁴	SW¼ SW¼ sec. 12, T. 28 N., R. 29 W., at Bower Mills bridge, 0.8 mi north of La Russell	11-4-64	43.0	---	---	47	20
			11-3-82	71.1	360	---		

²Low-flow partial-record station. Previous discharge measurements not shown, except for 1964 seepage-run data⁴Continuous-record streamflow-gaging station since April 1957

TABLE 4 (continued)

Map no. (fig. 5)	Station name	Location	Date	Discharge, (ft ³ /s)	Specific conductance (micromhos)	Water temperature (degrees Celsius)	7-day low-flow in ft ³ /s, for indicated recurrence interval, in years	
							2	10
9	Dougher Branch	SW¼ sec. 10, T. 26 N., R. 26 W., at county road ford, downstream from sewage-treatment facility, 1.5 mi west of Aurora	7-15-82	.5	600	24.0	---	---
			11-1-82	.7	700	18.5	---	---
10	Dougher Branch	SE¼ sec. 8, T. 26 N., R. 26 W., at bridge on County Highway P, 0.25 mi north of Verona	7-15-82	0 (pools)	---	---	0	0
			11-1-82	0 (pools)	---	---	---	---
11	Spring River	NE¼ SE¼ sec. 25, T. 27 N., R. 27 W., at county road bridge, 4 mi east of Freistatt	11-1-82	20.8	370	18.0	---	---
12	Browning Hollow	SW¼ NW¼ sec. 30, T. 27 N., R. 26 W., at county road ford, 4 mi east of Freistatt	7-14-82	0	---	---	0	0
			11-1-82	0	---	---	---	---
13	Spring River	On line between secs. 12 and 13, T. 27 N., R. 27 W., at county road bridge, 1 mi southeast of Hoberg	11-4-64	3.6	360	16.0	4.5	---
			7-14-82	14.0	330	21.5	---	---
			11-2-82	18.7	360	16.0	---	---
14	Spring River	NW¼ NE¼ sec. 11, T. 27 N., R. 27 W., at county road bridge at Hoberg	11-2-82	17.3	370	16.5	---	---
15	Spring River	SW¼ sec. 2, T. 27 N., R. 27 W., at bridge on County Highway H, 1 mi northwest of Hoberg	11-2-82	18.5	370	16.5	---	---
16	Honey Creek	SW¼ NE¼ sec. 35, T. 27 N., R. 25 W., at bridge on County High- way 22 at Marionville	11-1-82	0 (pools)	---	---	0	0

absence of terrace development. The lack of streamflow and channel development indicates rapid infiltration of precipitation, rather than surface runoff.

As measured during the summer of 1982, the potentiometric surface for the shallow aquifer, is well below the elevation of surface streams in upland areas, with the exception of the Baldwin Park area. In areas where the potentiometric surface is well below stream level, stream channels are dry. The headwaters of streams draining the Baldwin Park area, where the potentiometric surface is intersected by surface streams, have flow and a more normal channel development. Downstream from the Baldwin Park area the potentiometric surface declines rapidly and flow is lost to the subsurface.

The upland area of the Spring River basin is developed on permeable soil and bedrock, and the potentiometric surface of the shallow aquifer is well below the level of most surface streams. As a result, much of the upland area is an area of rapid recharge to the shallow aquifer (fig. 6). Dissolved contaminants could enter the groundwater system with recharge, but relatively insoluble contaminants probably would be limited to entering the groundwater system, in association with fine sediment, at places such as sinkholes and losing streams, where solution channels are near the surface.

Major Streams

Major streams draining the area are either recharge or discharge areas for the shallow aquifer. The Spring River, upstream from Spring River Spring, has characteristics of streams in the upland area. Spring River Spring, in the NE¼ NW¼ NW¼ sec. 28, T. 26 N., R. 26 W.,

marks the intersection of Spring River and the potentiometric surface of the shallow aquifer. As shown in table 3, Spring River is perennial downstream from Spring River Spring, and flow increases to the vicinity of site 11 (fig. 5), near the mouth of Browning Hollow. In Spring River, downstream from this point, there is loss of flow that persists to the confluence of Spring River and Williams Creek. This area of flow loss in Spring River coincides with a low in the Mississippian potentiometric surface and an area of flow loss in Honey Creek, which enters Spring River in this reach.

Dye-Tracer Studies

A dye-tracer study was made on the Spring River flood plain near Verona in an attempt to characterize subsurface water movement in the vicinity of the chemical plant wastewater lagoons. Dye was introduced into the alluvium through a backhoe trench excavated near the lagoon site. The trench, 6 ft deep, the bottom 2.5 ft exposing water-bearing alluvial gravel, was excavated on the east side of a drainage ditch, formerly a meander channel of Spring River, and approximately 150 ft south of the fence marking the north boundary of the chemical plant. The lagoons are believed to have been west of this drainage ditch.

Two and a half gallons of rhodamine WT dye were introduced into the water-bearing gravel in the trench on October 5, 1982, and packets of activated charcoal were placed at 17 points in the upstream part of the Spring River basin (fig. 7). To avoid confusion, only the points considered necessary to trace dye movement are shown on the map. Dye passing through the packets is adsorbed on the activated charcoal and can be detected in the laboratory, with a fluorometer. Charcoal packets were

TABLE 4 (continued)

Map no. (fig. 5)	Station name	Location	Date	Discharge, (ft ³ /s)	Specific conductance (micromhos)	Water temperature (degrees Celsius)	7-day low-flow in ft ³ /s, for indicated recurrence interval, in years	
							2	10
24	Honey Creek	SE¼ sec. 2, T. 27 N., R. 27 W., at county road bridge, .5 mi northeast of Hoberg	11-4-64 11-2-82	0 0 (pools)	--- ---	--- ---	0	0
25	Honey Creek	SW¼ sec. 2, T. 27 N., R. 27 W., at bridge on County Highway H, .5 mi northwest of Hoberg	11-2-82	0 (pools)	---	---	0	0
26	Spring River	On line between secs. 3 and 34, T. 27 N. and 28 N., R. 27 W., at county road bridge, 1.5 mi northwest of Hoberg	11-4-64 11-2-82	2.0 17.5	340 370	16.0 16.5	---	---
27	Unnamed Creek	On line between secs. 29 and 32, T. 28 N., R. 27 W., at county road bridge, 2.5 mi east of Stotts City	11-2-82	0	---	---	0	0
28	Williams Creek	SE¼ sec. 25, T. 28 N., R. 27 W., at bridge on State Highway 39 at Mount Vernon	11-2-82	3.5	370	16.0	2.0	0.8
29	Williams Creek ²	NW¼ NE¼ sec. 34, T. 28 N., R. 27 W., at bridge on County Highway V, 2 mi west of Mount Vernon	11-4-64 11-2-82	3.8 8.8	330 440	18.0 16.0	4.7	2.0
30	Big Spring	NE¼ sec. 28, T. 28 N., R. 27 W., at county road ford, 3 mi north- west of Mount Vernon	11-3-82	25.6	370	14.5	16	9.0
31	Spring River	On line between secs. 20 and 29, T. 28 N., R. 27 W., at county highway bridge, 2.5 mi northeast of Stotts City.	11-3-82	50 ³	380	12.5	---	---

²Low-flow partial-record station. Previous discharge measurements not shown, except for 1964 seepage-run data.

³Additional flow in separate channel, estimated to be approximately 12 ft³/s, was not measured but is included in this figure.

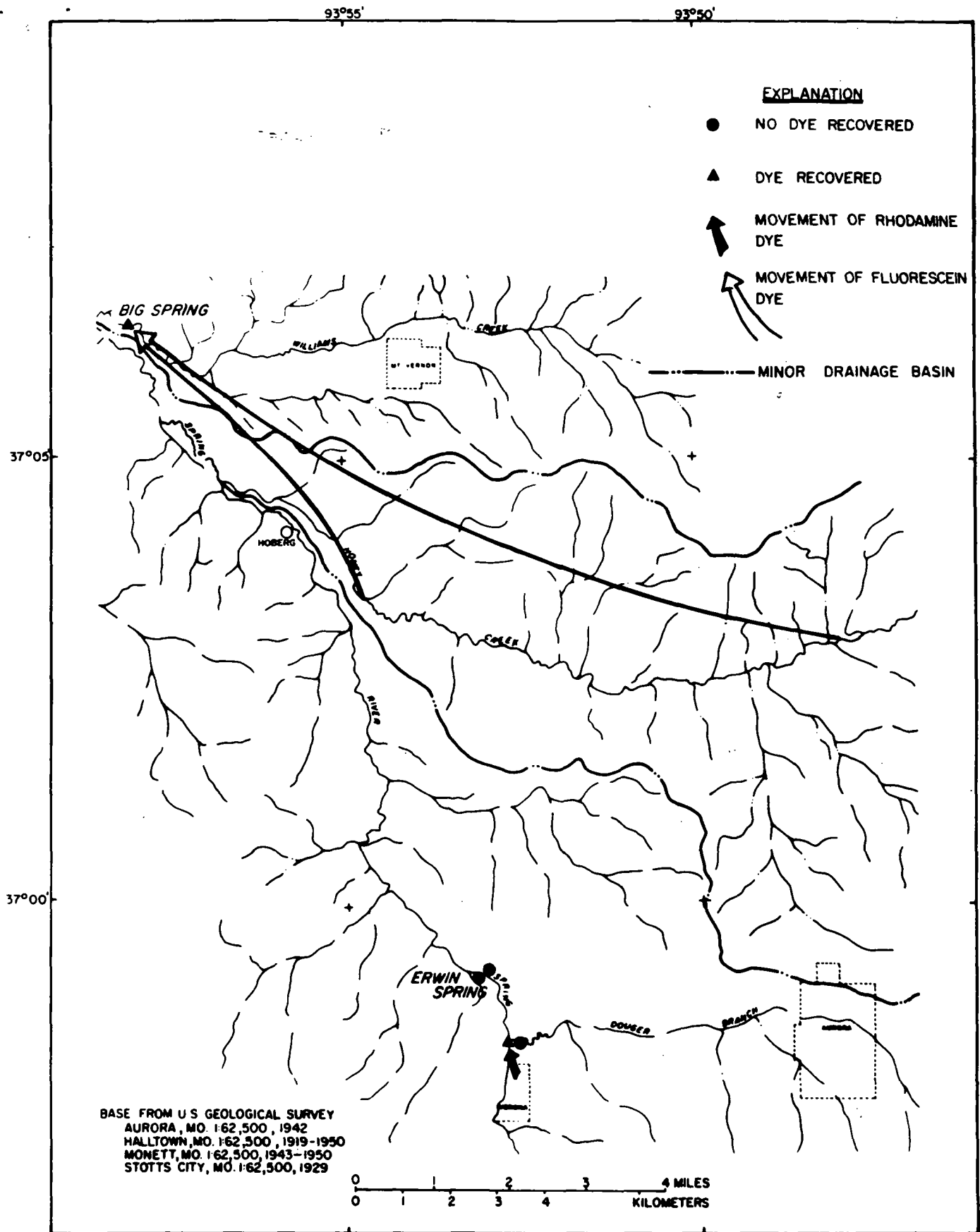


Figure 7. Movement of dye from dye traces in the upstream part of the Spring River basin, November-December 1982.

accuracy of the estimates. In losing reaches of the streams, frequency data generally were not estimated, because of inadequate field data and increased variability of low-flow patterns in losing reaches.

The seepage-run measurements were made during a time of small evapotranspiration losses; therefore, they are excellent indicators of stream reaches where surface flow is lost to aquifers. The stream reaches where significant surface-water losses occurred, as defined by the discharge measurements (fig. 5), were between sites 9 and 10 on Douger Branch, where effluent from the Aurora sewage-treatment plant (about 0.7 ft³/s or 0.5 mgd) was lost. The measurements also show that there was little or no increase in flow, and possibly some loss, in the reach of Spring River, between sites 13 and 26, which is in the general vicinity of the losing reach on Honey Creek.

From field observations made during the fall of 1978, the summer of 1982, and the November 1982 seepage run, it is estimated that Honey Creek discharged 10.1 ft³/s, or 6.5 mgd, of water into aquifers. Surface flows greater than this in upper Honey Creek basin will remain on the surface and drain into Spring River. This approximation is based primarily on hydrologic conditions during 1982, a time of greater-than-normal rainfall and groundwater levels. The volume of surface flow discharged into aquifers could be greater if the groundwater reservoir were depleted during drought conditions.

MOVEMENT BETWEEN GROUND- WATER AND SURFACE WATER

Upland Areas

Solution-related weathering characteristics of exposed limestone bedrock

are primarily responsible for the extensive interaction between surface runoff and shallow groundwater, in the upstream part of the Spring River basin. According to Harvey (1980), groundwater recharge in karst areas of the Springfield Plateau occurs in three ways: primarily through sinkholes; in upland areas devoid of sinkholes, by infiltration, but with solution-developed permeability; and through losing streambeds.

Sinkholes are uncommon in the study area and are of little significance to groundwater recharge. Two sinkholes are north of Aurora, in the NE $\frac{1}{4}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 36, T. 27 N., R. 26 W., and a broad, poorly defined sinkhole is west of Hoberg, in the SW $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 10, T. 27 N., R. 27 W. In the *Geology* section of this report it is indicated that there was pre-Pennsylvanian karst development throughout the study area, as shown by Pennsylvanian-sandstone fills in sinkholes in Mississippian bedrock. There is no evidence of significant groundwater recharge through these filled sinkholes, but their existence is evidence of solution-related permeability in the underlying limestone. Groundwater recharge through permeable soil and bedrock resulting from solution-related weathering probably is the primary recharge mechanism.

Upland streams, with the exception of those draining the Baldwin Park area in Aurora, were dry during the summer and fall of 1982, though precipitation was greater than normal. As described by Harvey, Williams, and Dinkel (1977, p. 8), channel development in these upland streams is characteristic of streams that lose flow to the subsurface. Characteristics of such streams include poorly defined stream channels, poor sorting of stream sediments, scarcity of phreatophytes, limited accumulation of fine sediments in stream-channel and flood-plain deposits, and a general

TABLE 5
Suspended-sediment data for the Spring River and Honey Creek, August 1982

Date	Time	Streamflow, instantaneous (ft ³ /s)	Sediment, suspended (mg/l)	Sediment, discharge, suspended (T/day)	Sediment, suspended sieve diameter % finer than 0.062 mm	Sediment suspended fall diameter % finer than 0.016 mm	Sediment suspended fall diameter % finer than 0.004 mm	Sediment suspended fall diameter % finer than 0.002 mm
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07185250 — Map No. 2 (fig. 1) — Spring River below Verona, MO (Lat. 36° 58' 26", Long. 093° 43' 54")

Aug. 1982

04	1230	8.3	37	0.83	76	---	---	---
07	1100	115	53	16	97	---	---	---
07	2030	270	125	91	98	---	---	---
08	1030	153	58	24	100	---	---	---
13	1620	280	158	119	97	---	---	---

07185300 — Map No. 3 (fig. 1) — Spring River near Hoberg, MO (Lat. 37° 03' 30", Long. 093° 50' 08")

Aug. 1982

04	1530	14	20	0.76	77	---	---	---
07	1830	28	58	4.4	100	---	---	---
07	2200	205	401	222	99	---	---	---
08	0815	45	61	7.4	97	---	---	---
14	0830	208	60	34	99	---	---	---
27	1130	275	263	195	70	---	---	---
27	1400	780	785	1650	83	---	---	---
28	0900	150	70	28	54	---	---	---

07185350 — Map No. 4 (fig. 1) — Honey Creek near Hoberg, MO (Lat. 37° 02' 27", Long. 093° 49' 49")

Aug. 1982

04	1430	4.0	8	0.09	37	---	---	---
07	1830	15	88	3.6	97	---	---	---
07	2200	30	60	4.9	97	---	---	---
08	1030	45	37	4.5	100	---	---	---
13	1735	805	392	852	99	78	53	43
27	1130	---	111	---	46	---	---	---
27	1400	---	88	---	72	---	---	---
27	1700	---	112	---	67	---	---	---

07185700 — Map No. 6 (fig. 1) — Spring River at La Russell, MO (Lat. 37° 09' 13", Long. 094° 03' 21")

Aug. 1982

03	1600	79	14	3.0	70	---	---	---
07	2200	102	46	13	74	---	---	---
08	0700	115	28	8.7	98	---	---	---
08	1400	320	109	94	98	---	---	---
13	1430	972	361	947	99	84	61	50
14	0838	1600	286	1240	100	75	61	49

CHARACTERISTICS OF THE SPRING RIVER

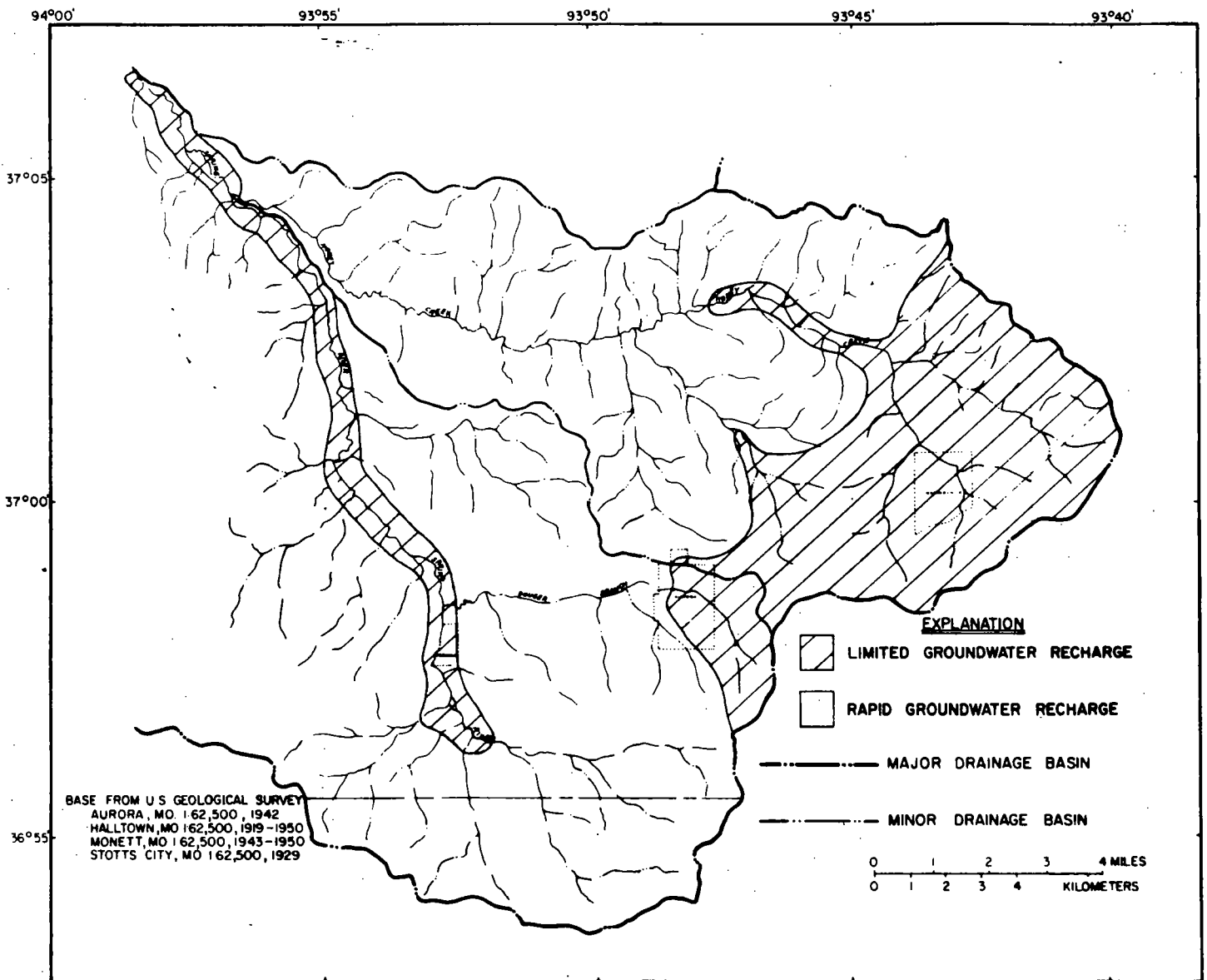


Figure 6. Regional groundwater recharge in the upstream part of the Spring River basin.

collected and replaced at 7-day intervals from October 5, 1982 to December 1, 1982.

Rhodamine WT dye was first recovered in the drainage ditch, approximately 500 ft downstream from the injection point, on October 13, 7 days after the dye was introduced into the trench. Dye was not recovered at

any other station until November 24, when it was recovered from a charcoal packet from Spring River, 2700 ft downstream from the point of injection. On the same date, dye was also recovered from charcoal packets farther downstream in Spring River.

The movement of dye from the injection point to Spring River indicates

NEED FOR ADDITIONAL WORK

The source of recharge for Erwin Spring needs to be identified. Erwin Spring was known to be contaminated with organic wastes during operation of the waste lagoons. However, dye injected into the alluvium near the lagoons slowly migrated to the Spring River, but was not recovered from Erwin Spring. Onsite reconnaissance of possible spring recharge areas, and subsequent dye-tracer studies, including one from the Spring River at Verona, probably are needed to determine groundwater movement to Erwin Spring.

A more detailed understanding of groundwater movement in the Baldwin Park area may be needed because of the possibility of dioxin contamination of landfill wastes in the park. Dye injected into the landfill site would trace groundwater movement. Water-level recorders installed on mine shafts and wells in the Baldwin Park area would be useful in determining groundwater response to rainfall.

During this study no attempt was made to collect water samples from

springs and wells to determine potential contamination by dioxin; however, due to presence of solution openings in limestone, the possibility of transporting dioxin-contaminated fine particles through the solution openings into the groundwater system cannot be ignored. In future studies, therefore, water samples need to be collected for dioxin analyses, from springs and wells, to ensure this potential will be evaluated.

Fine sediments eroded from waste sites may be a primary transport medium for dioxin. Additional dioxin analyses are needed to determine if dioxin is present in area streams and in suspended sediments leaving waste-disposal sites. Fine sediments appear to move in streamflow out of the study area, or to be deposited on area flood plains. Therefore, additional soil and sediment samples need to be collected for dioxin analyses, from Spring River flood plains and impoundments, where fine materials are accumulating downstream from the study area.

SUMMARY AND CONCLUSIONS

The U.S. Environmental Protection Agency has confirmed that soils, streambed material, and fish in the upstream part of the Spring River basin are dioxin contaminated. Solubility of dioxin is only 0.2 $\mu\text{g/L}$, but it can be transported in the hydrologic system, adsorbed on sediments. Geological, hydrological, and sediment information was collected during this study, to provide better understanding of the possible transport mechanism for dioxin in the area.

Pennsylvanian channel-sand and sinkhole deposits occur throughout much of the area. The shallow aquifer (composed primarily of Mississippian limestones) extends more than 400 ft downward from the surface and is separated from the deep aquifer (Ordovician and Cambrian dolomites and sandstones) by relatively impermeable Mississippian silty limestones and shales. Water levels in the shallow aquifer are 10 to 50 ft below land surface. In most of the upland areas, rapid recharge to

water movement through alluvial material, as opposed to a conduit-type movement through solution channels in bedrock. No dye was recovered from Erwin Spring or other springs approximately 8000 ft downstream from the point of injection. These springs were known to have been contaminated during operation of the lagoons.

The Honey Creek dye-tracer study was made in an attempt to trace water loss in Honey Creek, downstream from the Missouri State Highway K bridge. Seepage-run data collected during November 1982 showed a loss of 8.2 ft³/s, or 5 mgd, of flow in Honey Creek, between the Highway K bridge and the town of Hoberg. Flow measurements made at points between the Highway K bridge and Hoberg indicate that flow loss does not occur at one discrete point, but gradually, along the stream reach.

Five pounds of dry fluorescein dye was released in Honey Creek, at the Highway K bridge, on November 10, 1982 (fig. 7). Dye was recovered, using

activated charcoal packets, as described for the Spring River dye-tracer study. Fluorescein dye was recovered from Big Spring, about 3 mi northwest of Mt. Vernon, on November 17, 1982, 7 days after it was introduced into the stream.

In 7 days or less, the dye moved 9.2 mi between the Highway K bridge and Big Spring. Flow rates measured in the Honey Creek dye trace were more rapid than those measured in alluvial materials, in the Spring River dye trace. This indicates a conduit-type subsurface water movement, probably through solution channels in limestone bedrock rather than flow through alluvial materials; fine sediments and contaminants can be transported through such a subsurface environment.

The proximity of the losing reach of Honey Creek to the losing reach of Spring River would appear to indicate that water loss from the two streams is related, but to date (1983), no dye-tracer studies have been made on the reach of Spring River to verify such a connection.

SEDIMENT CHARACTERISTICS

Data collection for detailed quantification of the sediment characteristics of the area was beyond the scope of this report, because the study was of short duration. For a general appraisal, however, sufficient suspended- and streambed-sediment data were collected from Spring River and Honey Creek, at sites shown in figure 1.

Suspended-sediment samples were collected at four sites, using techniques described by Guy and Norman (1970), and were analyzed for concentration and particle size, according to methods described by Guy (1969). Briefly,

collecting involved lowering and raising, at a constant rate, a handheld suspended-sediment sampler, at quarter points across the stream. All samples, except the first set (August 3 and 4), were collected during periods of runoff. Table 5 summarizes results.

The average annual sediment yield estimated by Gann and others (1974), for the Spring River basin is 100 to 300 tons/mi²/yr. This small yield and the relatively small concentrations listed in table 5 reflect the predominantly pasture and forest land use and sparse population in the basin.

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Classification of sediment sizes according to Guy (1969) is as follows:

Class	Size, in millimeters
Clay	0.00024-0.004
Silt	0.004-0.062
Sand	0.062-2.0
Gravel	2.0-64
Cobbles	64-256
Boulders	Greater than 256

Suspended-sediment particles in samples collected from Spring River and Honey Creek generally were less than sand size. Only one high-flow sample from Honey Creek, near Hoberg, and two from Spring River, at La Russell, contained sufficient sediment for detailed size analysis. Percentages in each size class for these samples were 5 to 60 percent clay, 40 to 50 percent silt, and about 1 percent greater than silt size.

Spring River, at La Russell, the only streamflow-gaging station with long-term records, had suspended-sediment discharges ranging from 3.0 to 1240 ton/d. The minimum occurred at a discharge of 79 ft³/s, 1.7 times the 7-day Q₂, which is the average minimum flow for 7 consecutive days, with a recurrence interval of 2 years; the maximum, at a discharge of 1600 ft³/s, which is 6.7 times the long-term average.

Streambed sediment samples were collected at six sites and analyzed for dioxin and particle size. The samples were collected by manually scooping streambed sediment from 5 to 10 locations at each site and compositing them. Because of the greater likelihood of dioxin being associated with finer sediments, only streambed locations containing the finer sediments were sampled. Consequently, particle sizes shown in table 6 do not accurately represent the range of particle sizes of the streambed sediments. In reality, because the streambed at each site consists primarily of sand- to boulder-size materials, samples containing particles finer than sand were difficult to obtain. There appear to be few reaches in the Spring River, upstream from La Russell, where velocities are sufficiently slow for deposition of fine sediments.

Analyses indicate dioxin concentrations were less than the analytical detection levels at each site. The results are inconclusive, however, because only six samples were analyzed and detection levels were relatively high. Finer dioxin-contaminated sediments may be transported out of the area by streamflow, or they may be deposited on flood plains or in downstream impoundments during periods of flooding.

TABLE 6

Particle size of streambed sediments and associated concentrations of dioxin

(Samples collected by U.S. Geological Survey, September 14, 1983; particle size determined by U.S. Geological Survey. Dioxin samples submitted to U.S. Environmental Protection Agency for analyses.)

Map no. (fig. 1)	Station no.	Station name	Dioxin (ppt) ¹	Percentage of sediment finer than indicated sizes in millimeters												
				0.002	0.004	0.008	0.016	0.062	0.125	0.250	0.500	1.000	2.000	4.000	8.000	32.000
1	07185200	Spring River at Verona, Mo.	< 13	8	12	14	27	55	57	59	62	64	67	75	88	100
2	07185250	Spring River below Verona, Mo.	< 10	—	—	—	—	6	7	10	15	32	54	67	74	88
3	07185300	Spring River near Hoberg, Mo.	< 9	11	14	18	32	68	69	69	71	72	76	82	91	100
4	07185350	Honey Creek near Hoberg, Mo.	< 23	2	3	3	5	10	10	18	36	43	51	62	80	100
5	07185370	Spring River near Mt. Vernon, Mo.	< 8	7	10	11	20	39	41	45	51	56	67	79	94	100
6	07185700	Spring River at La Russell, Mo.	< 8	4	8	10	18	41	42	46	49	49	52	53	58	100

¹ppt = parts per trillion

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the shallow aquifer is through permeable soil and bedrock, as indicated by dry streambeds and a potentiometric surface well below the level of the streambeds. An exception is the Baldwin Park area in Aurora, where upland streams intersect the water table. Carbonate solution openings and abandoned mines provide opportunities for rapid movement of groundwater in the basin, but there is no indication of interbasin flows, except possibly east of Aurora.

Water movement in the shallow aquifer generally follows the topography, and the larger streams are drains. In the downstream part of Honey Creek, however, the streambed is higher than the potentiometric surface. A seepage run made during 1982 showed a loss of 8.2 ft³/s, or about 5 mgd, in the lower part of Honey Creek, and it is estimated that the solution channels beneath the creek probably will divert surface flow of 10.1 ft³/s, or 6.5 mgd. There was little or no increase in flow, and possibly a loss, in the reach of Spring River in the general vicinity of the losing reach of Honey Creek. The seepage run also revealed a loss in flow in the downstream part of Douger Branch near Verona. Dye injected into the losing part of Honey Creek was recovered at Big Spring, about 3 mi northwest of Mt. Vernon. The dye traveled a straight-line distance of 9.2 mi in about 7 days, indicating a conduit-type subsurface connection provided by solution openings in the limestone.

Dye injected into the alluvium near a waste lagoon at Verona reached the Spring River, 2700 ft downstream, in about 50 days. In this case, dye movement reflects the slower travel

time through the alluvium, compared to the conduit-type movement indicated for Honey Creek.

Water samples from springs and wells were not collected to determine presence of dioxin. Due to presence of solution openings in the limestone, the possibility that dioxin-contaminated fine sediments may be transported through them cannot be ignored. In future studies, therefore, water samples need to be collected and analyzed for dioxin, to evaluate this potential.

Sediment yields generally are small in the upstream part of the Spring River basin. Suspended-sediment discharges at La Russell ranged from 3.0 ton/d, at a flow of 1.7 times the 7-day Q_2 , to 1240 ton/d, at a flow of 6.7 times the long-term average. Suspended-sediment particles in the Spring River and Honey Creek generally were less than sand size. The streambed sediments generally were larger than silt size. Fine sediments probably are transported out of the area by streamflow, or deposited on flood plains or in downstream impoundments during flooding, or both.

Additional dye-tracer studies are needed to determine the source of recharge to Erwin Spring and the groundwater flow paths in the Baldwin Park area. Dioxin analyses of sediment suspended in runoff from waste sites, suspended sediment in area streams, flood-plain soil, bottom material in downstream impoundments, and spring and well waters are needed to provide additional information about the occurrence, transport, and deposition of dioxin in the area.

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